Acoustic Seaglider: Philippine Sea Experiment

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LONG-TERM GOALS

Within the Ocean Acoustics Deep Water program, the long-term goals are to understand the physics of long-range, broadband propagation in deep water and the effect of oceanic variability on acoustic propagation.

The project will seek to develop new techniques and technologies to improve the ability to measure and characterize the highly dynamic ocean environment and understand the effect of ocean variability due to mesoscale eddies, tides, currents, and internal waves on the acoustics. An accurate characterization of the ocean improves the predictability of acoustic propagation through it and, in turn, enables inversions for oceanic properties from acoustic receptions. The long-term goal is to use multiple platforms and techniques, old and new, acoustic and oceanographic, moored and mobile, to sense the ocean environment, and to understand the effect of oceanic fluctuations on deep-water acoustic propagation.

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OBJECTIVES

Six acoustic transceiver moorings were deployed in a pentagon shape as part of a large-scale tomography array in the northern Philippine Sea with an extensive distributed vertical line receiving array (DVLA) moored within the pentagon. Gliders recording acoustic data as well as measuring temperature and salinity were deployed, Figure 1. General objectives of the experiment are to understand the acoustic propagation in the Philippine Sea, an oceanographically complex and dynamic region, and to use the acoustic receptions to learn about the time-evolving nature of the oceanic environment, and thus, the effect of the latter on the acoustic propagation and coherence.

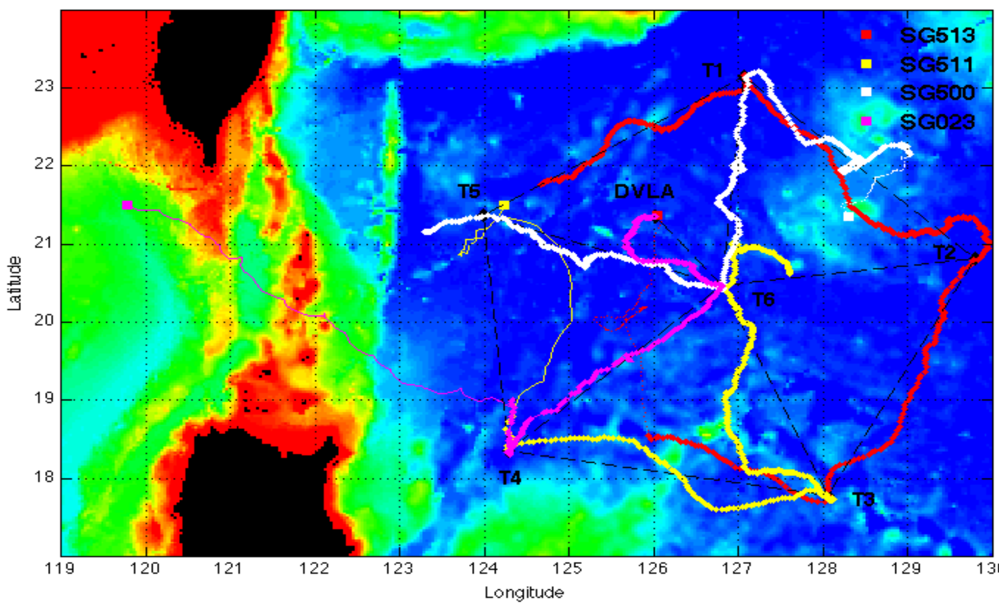

Figure 1. Plan view of the PhilSea10 mooring geometry, with six acoustic transceivers (T1, T2, … T6) and the DVLA. Four acoustic Seagliders (SG) were deployed and followed the indicated paths. Heavy dots indicate surface positions of gliders while collecting data. Light dots for SG500 and SG513 indicate the glider is diving but not collecting data. Light solid lines for SG023 and SG511 indicate surface-drift paths. Squares indicate recovery positions.

Specific objectives of this project are:

1. Deploy, operate, and recover four acoustic seagliders as part of PhilSea10.

2. Estimate the positioning precision and accuracy of the gliders underwater using the received signals from the various distant moored sources to determine whether precision is adequate for tomographic inversions.

3. Utilize acoustic transmissions from fixed acoustic sources to mobile receivers to map the acoustic arrival pattern as a function of range and depth. Observe wavefront scattering at these various positions in conjunction with the complementary full-ocean depth observations obtained on the DVLA.

4. Identify ray arrival peaks from the glider acoustic travel-time data. These ray identifications will be used in the joint navigation and tomographic reconstruction solution.

APPROACH

The seven moorings were deployed in April 2010 and were in-place for one year. Seagliders were deployed November 2010 – April 2011, Figure 1. Each glider was equipped with an acoustic recording system (ARS) to record the moored source transmissions, as well as temperature, salinity and pressure sensors (from which sound speed is calculated). The ARS data provide the travel times for use in long-range positioning and tomographic inversions; the point data will provide a time-evolving characterization of the variable upper ocean between the transceivers. Objective mapping and (simple) Kalman filtering techniques will be explored to utilize the unique time-space sound speed sampling of the Seagliders to generate snapshots of the time-evolving oceanic environment.

This estimation of the oceanic environment will form the basis of acoustic propagation calculations for comparison with received acoustic data. A solid understanding of the acoustic propagation will enable inversions for the structure of the ocean volume encompassed by the transceivers, i.e., acoustic tomography. The acoustic Seagliders will supplement the moored sensors, serving as additional nodes in the tomographic array, and thereby multiplying the number of cross-sectional acoustic paths in the study area (Cornuelle, 1985; Gaillard, 1985; Cornuelle et al., 1989; AMODE-MST Group, 1994; Duda et al., 1995).

WORK COMPLETED

The gliders were operated successfully in PhilSea10, albeit two had to be recovered early. The acoustic data are good. They have been processed to obtain arrival patterns. Measured arrival peaks have been unambiguously identifed with predicted ray arrivals. Travel time offsets between the measured and predicted arrivals have been obtained for the entire data set; the latter offset is a measure of the range uncertainty, i. e, glider position. Glider temperature and salinity profiles have been processed, though work to remove outliers continues.

Initial results from just-after-recovery were presented at the Kona Oceans11 meeting, Howe et al., 2011. More recent results were presented at the Acoustics'12 conference in Hong Kong. A manuscript for the JASA special issue on Deep Water Acoustics will be submitted in the next month.

RESULTS

Because every reception on the glider is for a different and unique range and depth, the "tracking" of ray arrivals that is common for fixed-path tomography is not possible. We have found though that the measured arrival patterns (especially the dispersion of arrivals) are close enough to predicted ray arrivals that an unambiguous ray identification can be made, Figure 2. This particular example is "rich" in arrivals because of relatively large range and deep receiver depth. Clear in this figure are strong diffracted arrivals associated with late arriving rays that nominally turn below the receiver.

In order to perform tomography inversions of the acoustic data for sound speed, we expect to have to perform a joint estimation problem where both the sound speed field and glider positions/velocities are solved for simultaneously. A preliminary step, though one that does not use the inherent precision of the travel time measurements, is to first estimate glider position from the multiple transmissions. A still

simpler first step is to determine the offset between the measured and predicted travel times (or equivalently range, using a nominal sound speed of 1500 m/s). This offset is plotted for each glider and each reception in Figure 3. The rms value is 434 ms (651 m). This has two components. First, the smaller component is that associated with the expected sound speed perturbations, in this case ~80 ms rms (120 m rms; B. Powell, personal communication). The second component is the difference betweein this and thte total (using variances) giving 431 ms (646 m); this is attributed to the difference between the actual glider position and the position estimated from its kinematic model (based on dead-reckoning taking into account roll, pitch, heading, buoyancy, drag, GPS surface positions, etc). This range offset is, for reference, roughly the same as the difference between the dead-reckoned surface position and the actual GPS position of the glider. The latter is used to calculate a dive-time-space averaged velocity, that is in fact a complicated nonlinear average of the absolute water velocity felt by the glider along its path.

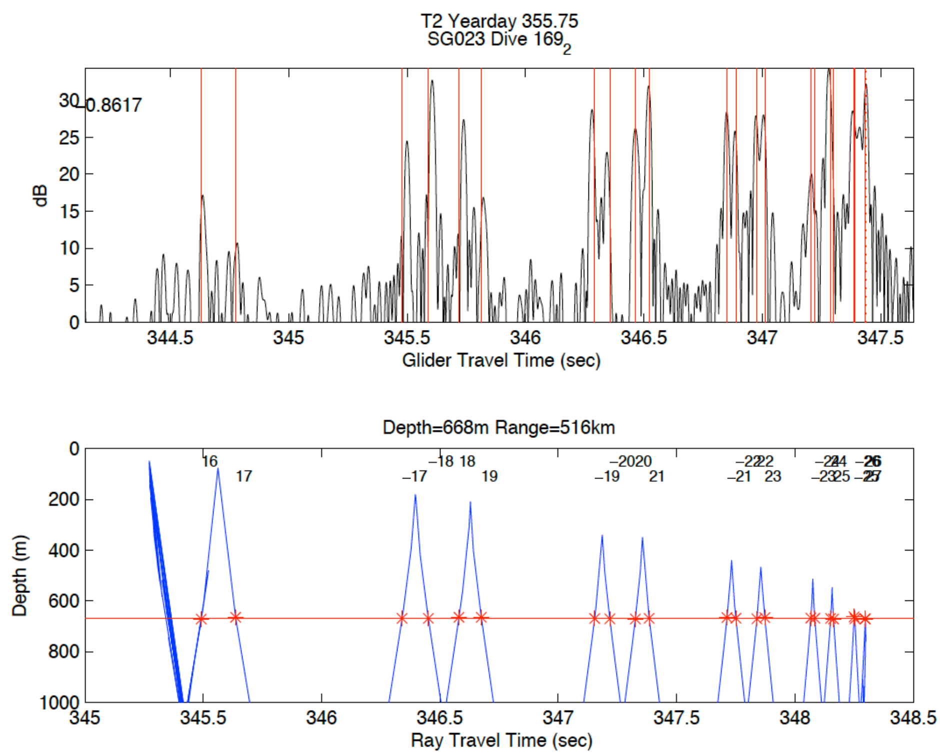

Figure 2. Received acoustic data (top) on SG023 from the 1800 transmission of source T2 on 2010 Yearday 355 at a range of 516 km and glider depth of 668 m. Vertical lines indicate alignment with predicted eigenrays. Stars mark the intersection of the predicted timefront pattern in the upper ocean (bottom) with a horizontal line indicating the depth of glider at the time of the reception. The Ray ID for these identified eigenrays are indicated.

Given large depth-dependent tidal velocities (e.g., as observed with moored ADCPs, J. Colosi, personel communication), it should not have been unexpected that during the ~6.2 hour dives, the glider would be “blown” around off its nominal path by time and space varying currents, currents that are otherwise unobserved.

This means that as we move forward in the analysis, we will have to construct a suitable water/glider velocity model, probably based on statistics derived from the moored ADCP data. This will help interpolate over the ~10 minutes between each sequential source transmission, as well as the 3 hours between nominal transmission times on every other day.

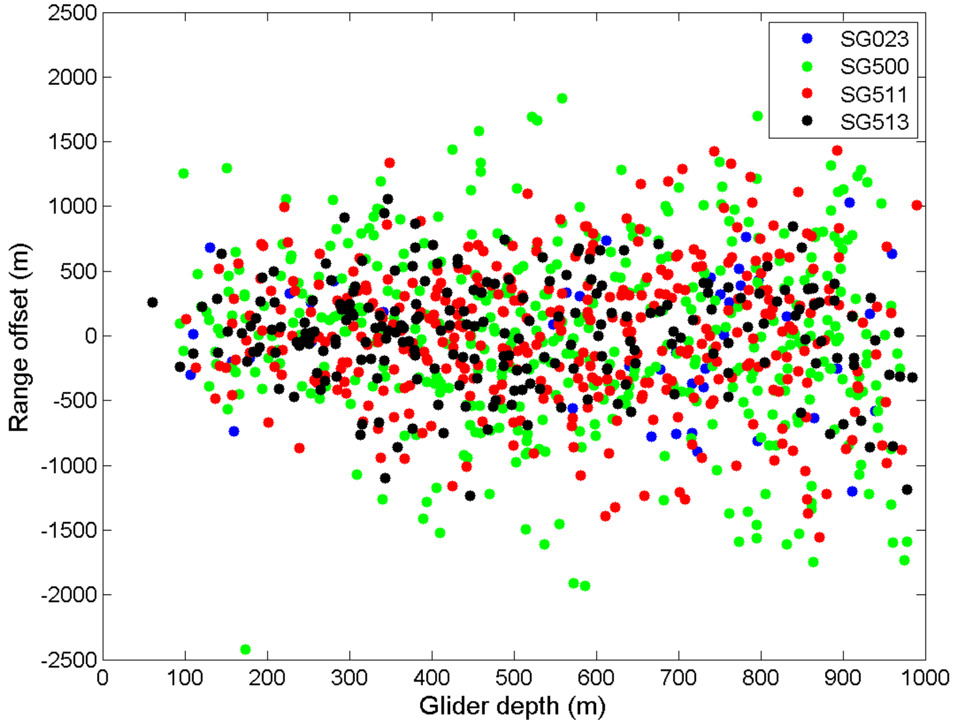

Figure 3. Range offset vs depth for the four gliders. There is a slight dependence on depth, or time to most recent GPS fix.

IMPACT/APPLICATIONS

Results to date support the validity of "underwater GPS" / RAFOS-2, namely that precise, O(~100 m), long-range navigation and positioning is achievable using multiple low frequency broadband acoustic sources and the resulting multipath arrivals (Duda et al., 2007).

TRANSITIONS

The company manufacturing and selling the Seaglider, iRobot, Inc., is in the process of commercializing a hydrophone system for the Seaglider. Some of the lessons learned from our use is helping in this process.

RELATED PROJECTS

This project is just one of many associated with the ONR PhilSea10 experiment.

Some of the investigators on this project were involved with a recently completed CEROS (National Defense Center of Excellence for Research in Ocean Sciences) project, *Simultaneously Improving Glider Position Estimates and Ocean State Forecasts*, PI Pat Cross. In this project, a glider was tracked relative to bottom transponders with similar significant position offsets found.

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